

## CAN DILEPTON SUPPRESSION BE SEEN IN HEAVY ION EXPERIMENTS ?

**Abhijit Bhattacharyya<sup>a1</sup>, Jan-e Alam<sup>b2</sup>, Sibaji Raha<sup>a3</sup> and Bikash Sinha<sup>b,c4</sup>**

a) Department of Physics, Bose Institute

93/1 A.P.C.Road

Calcutta 700 009, INDIA

b) Variable Energy Cyclotron Centre

1/AF, Bidhannagar, Calcutta - 700 064, INDIA

c) Saha Institute of Nuclear Physics

1/AF, Bidhannagar, Calcutta - 700 064, INDIA

## ABSTRACT

Effects of finite temperature correction to the dilepton emission rate in ultrarelativistic heavy ion collisions have been looked into. It has been seen that although the  $\rho$ -peak in the dilepton spectra from the hadronic sector is suppressed at very high temperatures, almost no effect can be observed in the space time integrated count rate.

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<sup>1</sup>phys@boseinst.ernet.in

<sup>2</sup>jane@veccal.ernet.in

<sup>3</sup>sibaji@boseinst.ernet.in

<sup>4</sup>bikash@veccal.ernet.in

Very energetic collisions of heavy ions has become an intense field of study in recent times. The primary motivation for these investigations is to look for a putative new state of matter - Quark Gluon Plasma (QGP). But even more generally, the formation of highly excited hadronic matter at high temperature/density is an interesting issue in its own right. Dileptons and photons emanating from the reaction volume constitute an ideal means for studying the property of such hot matter - hadronic or QGP [1, 2, 3].

Recently Lee *et.al.* [4, 5] have calculated the finite temperature effects on the dilepton spectrum from the hadronic sector. They have used the results of QCD sum rule, at finite temperature, to arrive at the conclusion that the  $\rho$ -peak in the dilepton emission rate is suppressed in the hot hadronic matter. They have also claimed that this suppression may be observed in the experiments. Their result however refers to the static rate *i.e.* number of dileptons coming out from a particular space time point (characterised by a single temperature) of the hadronic part of the plasma. Unfortunately, there is no experimental way to measure this quantity. In experiments, one measures the total number of dileptons coming out of the plasma during the entire evolution time (*i.e.* starting from the time of formation upto freezeout). In this brief report we will look into the finite temperature effects on the experimental dilepton spectra using the same parameterisation as of Lee *et.al.* [4].

The most significant channel for the production of dileptons in the QGP sector is by annihilation of quark-antiquark pairs ( $q\bar{q} \rightarrow \mu^+\mu^-$ ) and by decays and binary reactions in the hadronic sector [2, 3, 6, 7, 8, 9]. As the emission rates from only the hadronic sector are modified by the temperature dependence of the form factors, we will consider only this sector in this work, as in [4]. Also, we confine our attention to the pion channel alone so as to compare our results with those of ref. [4].

The elementary crosssection for pion annihilation ( $\pi^+\pi^- \rightarrow \mu^+\mu^-$ ), assuming vector dominance, is given by [2]

$$\sigma_\pi(M) = F_\pi^2(M) \left[ 1 - \frac{4m_\pi^2}{M^2} \right] \sigma(M) \quad (1)$$

where

$$\sigma(M) = \frac{4\pi}{3} \frac{\alpha^2}{M^2} \left[ 1 + \frac{2m_l^2}{M^2} \right] \left[ 1 - \frac{4m_l^2}{M^2} \right]^{1/2} \quad (2)$$

and  $F_\pi(M)$ , the pion form factor, is given by

$$F_\pi^2(M) = \frac{m_\rho^4}{(M^2 - m_\rho^2)^2 + m_\rho^2 \Gamma_\rho^2} \quad (3)$$

where  $M$  is the invariant mass,  $m_l$  the lepton mass,  $m_\pi$  the pion mass,  $m_\rho$  the rho mass and  $\Gamma_\rho$  the rho decay width.

The thermal rate at fixed temperature  $T$  can be written as [2, 8]

$$\frac{dN}{d^4x dM^2 d^2 p_T dy} = \frac{1}{4(2\pi)^5} M^2 \left[ 1 - \frac{4m_l^2}{M^2} \right] \sigma_\pi(M) e^{-E/T} \quad (4)$$

where  $p_T$  is the transverse momentum and  $y$  is the rapidity.

We refer to the above expression as the "static rate", implying that the spatial/temporal variation of  $T$  is not taken into account.

Equation (4) gets modified at finite temperature through the temperature dependence of the form factor which, in turn, comes from the temperature dependence of the hadron masses, decay widths and coupling constants.

According to Lee *et.al.*, [4], the above quantity gets modified at high temperature by a factor of  $(1 - \delta)$  where  $\delta = T^2/6f_\pi^2$ ,  $f_\pi = 93\text{MeV}$  is the pion decay constant. As a result the height of the  $\rho$ -peak is suppressed.

Let us now look at the total emission rate of dileptons which is obtained by integrating eqn.(4) over the whole space-time volume. So,

$$\frac{dN}{dM^2 dy} = \int d^2 p_T d^4 x (1 - \delta) \frac{1}{4(2\pi)^5} M^2 \left[ 1 - \frac{4m_l^2}{M^2} \right] \sigma_\pi(M) e^{-E/T} \quad (5)$$

In the framework of Bjorken's hydrodynamics [10] the above expression takes the form [3]

$$\frac{dN}{dM^2 dy} = \frac{\alpha^2}{\pi^2} \int \tau d\tau r dr (1 - \delta) M T K_1(M/T) \left[ G(M^2) \Theta(H) + G(M^2) (1 - f_Q) \Theta(M) \right] \quad (6)$$

where  $f_Q(\tau) = \left(\frac{\epsilon_Q - \epsilon}{\epsilon_Q - \epsilon_H}\right)$  is the volume fraction of the quark matter in the mixed phase so that  $(1 - f_Q(\tau))$  is the amount of hadronic matter in the mixed phase at a time  $\tau$ .  $G(M)^2 = \frac{1}{12} F_\pi^2(M) \left[ 1 - \frac{4m_L^2}{M^2} \right]$ .  $\Theta(H)$  and  $\Theta(M)$  are the usual  $\theta$  functions corresponding to the purely hadronic and the mixed phases, respectively. If  $s_Q$  denotes the entropy density in the QGP phase at  $T = T_c$ ,  $s_H$  the entropy density in the hadronic phase at  $T = T_c$  and  $s$  the instantaneous entropy density, then  $\Theta(H) = \Theta(s_H - s)$  and  $\Theta(M) = \Theta(s - s_H) \Theta(s_Q - s)$ . All other terms have their usual meaning. The above equation is the space time integrated rate, the only quantity that is accessible in the experiment.

The freeze-out temperature  $T_F$  can not be *a priori* fixed without additional considerations. It is however expected that it should go to lower values with increasing mass numbers of the colliding nuclei. For our present purpose, we treat it as a parameter and use  $T_F = 50\text{MeV}$ . We have however verified that our conclusions (to follow) are quite insensitive to the actual values of  $T_F$  as long as  $T_F \leq 140\text{MeV}$ .

To summarise, using the parameterization of Lee et.al., we have calculated both the static and the space-time integrated emission rate for dileptons from the hadronic sector. The static rate has been calculated at  $T = 160$  and  $200\text{MeV}$ . It is true that the QCD sum rule, which is based on Operator Product Expansion (OPE), is valid only upto the limit where  $\delta \ll 1$ . But, to see the maximum suppression we have extended it to  $\delta \sim 1$  (*i.e.*  $T = 200\text{MeV}$ ). In figure 1a and figure 1b we have plotted the static rate and the space time integrated rate has been plotted in figure 2a and figure 2b. As seen from fig.1a and 1b, the  $\rho$ -peak is suppressed at finite temperature. This is the result obtained by Lee *et.al.* whence they have concluded that this suppression may be observed in the experiment. However, as we already mentioned in the above the experimentally accessible quantity is the total space-time

integrated rate (equation 6). We have plotted the results of the finite temperature effects on the total emission rates in figures 2a and 2b. It can be seen from these two figures that the suppression of the  $\rho$ -peak in the dilepton spectra is almost washed out. The magnitude of the surviving difference is so small that one can not expect to observe it in the experiment. During the evolution in the hadronic phase, the system spends a longer time in the lower temperature configuration where even in the static rate the difference is negligible. Most of the difference in the static rate is expected in the mixed phase which is long lived and also at the highest temperature achievable in the hadronic phase. But, the amount of hadronic matter in the mixed phase is not constant throughout the lifetime of the mixed phase, it starts with a very small amount and gradually whole system converts to the hadronic matter. Thus the difference in the static rate gets softened even in the mixed phase.

Recently, some calculations have been done in the same direction [11, 12]. In ref.[12], a suppression in the static dilepton emission rate has been obtained from a parameterization which assumes that the hadronic modes do not propagate beyond  $T_c$ . In such a situation, the static emission rate at  $T_c$  is thought to go to zero. This scenario however is not entirely consistent with the recent Lattice data [13] and the work of Gocksch [14], where the hadronic modes are argued to survive much beyond  $T_c$ . But more importantly, even for such a strong temperature dependence the difference almost gets washed out after space-time integration.

We thus conclude that in relativistic heavy ion collisions, one can not reasonably expect to observe a suppression in the dilepton emission rate due to the finite temperature modification of hadronic form factors. The space-time integration plays a crucial role in this game. It softens even very strong difference which occurs in the static rate. The importance of our work can be gauged from the large number of papers that have appeared in the literature in the recent times [4, 5, 11, 12]. All these authors have looked at only the static rate and gone on to draw far-reaching conclusions. It has even been suggested that the suppression in the dilepton emis-

sion rate be used as a signature for the partial restoration of chiral symmetry in hot hadronic matter formed in ultrarelativistic nuclear collisions [5]. We have shown here that upon a consistent handling of the space-time evolution of the system, such effects are almost impossible to discern in actual experiments. Our work should thus serve as a caution to the community that neglect of space-time integration may lead to optimistic expectations which are far from reality. Though the results obtained in this paper are confined to the pion annihilation process the main conclusion of this paper that the space-time integration softens the difference in the static rate will be valid for all the processes. The calculations carried out in this direction, so far, are of course based on some model or parameterization. But, keeping in mind the fact that the space-time integration kills even very strong difference, one expects that the conclusion of this work will not change whatever model one uses.

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**FIGURE CAPTIONS :**

1a) Static rate (at constant temperature) of dilepton emission, for  $\pi^+\pi^- \rightarrow \mu^+\mu^-$ , from the hadronic phase at RHIC energy at a temperature  $T = 160\text{MeV}$ . The solid line is for no finite temperature correction and the diamonds are with finite temperature correction.

1b) Same as 1a but at a temperature  $T = 200\text{MeV}$ .

2a) Thermal spectra of dileptons, for  $\pi^+\pi^- \rightarrow \mu^+\mu^-$ , without transverse expansion from a pion gas at RHIC energy for  $T_c = 160\text{MeV}$ . The solid line is for no finite temperature correction and the diamonds are with finite temperature correction. 2b) Same as 2a, but for  $T_c = 200\text{MeV}$ .

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